# POLYMERIC COATINGS TO IMPROVE THE STORAGE LIFE OF SOYBEAN SEEDS

By

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By

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Seed quality of soybean [*Glycine max* (L.) Merrill] can deteriorate anytime from the production field until the seeds are actually planted in the field. The maintenance of seed quality during storage is a major problem for the expansion of soybean into tropical and subtropical areas of the world, because in open storage, soybean seeds absorb moisture from the environment and deteriorate. The rate of deterioration of seeds is accelerated by high temperatures and the proliferation of storage microorganisms.

Conditioned storage with controlled temperature and relative humidity is frequently too expensive for soybeans, or it may not be available in some areas. For this reason, synthetic seed coating with moisture barriers to prevent seed deterioration during the long-term storage has received renewed interest.

The efficacy of polymers as moisture barriers and their effects on seed viability during storage was studied. Coated and non-coated soybean 'Tracy-M' and 'Century-84' seeds with different levels of initial moisture contents were stored in chambers at 85% RH and 25°C for periods up to 10 months. Two formulations of polyvinylidene chloride copolymer were tested. Daran® 8600 at 30 g $kg^{-1}$ of seed, when applied in a Vector Freund Hi-Coater®, with the addition of talcum ($D_1$) reduced the rate of uptake of moisture and invasion of storage fungi. Seed quality was maintained after treatment. However, a decline in seed viability was observed after four months of storage when seeds of 'Century-84' with moisture ≥ 100 g $kg^{-1}$ were coated with Daran® 8600 ($D_2$) or Daran® 220 ($D_3$), at 50 g $kg^{-1}$ of seed. No such decline was observed in 'Tracy-M' seeds coated with 58 g $kg^{-1}$ or 84 g $kg^{-1}$ initial moisture contents in $D_1$. Germination of the non-coated seeds was 0% after six months, whereas coated seeds germinated 60% and 66% after seven months for the low and high moisture levels, respectively.

Seed coating with Daran® 8600 ($D_1$) was shown to be a successful method to prevent seed deterioration in high relative humidities. The moisture content of the seed before coating and the thickness of the polymer layer were critical. The best results were obtained when the moisture level of the seed was between 58 g and 84 g $kg^{-1}$ fw and the polymer was applied at 30 g $kg^{-1}$ seed.

# INTRODUCTION

The soybean [*Glycine max* (L.) Merrill] became a crop of world-wide economic importance because of increased demand for cooking and salad oil during and immediately after World War II (Smith and Hyser, 1987). Among the eight major oilseeds traded in international markets, soybean has the largest volume. Unlike peanuts [*Arachis hypogaea* (L.)], whose share in the market decreased from 18% to 11% between the 1960s and 1980s, soybean increased from 32% to over 50% in the same period. The four major producers are the United States (63%), Brazil (16%), China (9%), and Argentina (6%). In Brazil, the area planted to soybean has expanded rapidly in the past few years (Delouche, 1975). Similar expansion was observed in Argentina (Smith and Hyser, 1987).

Soybean production in the past was mainly confined to the northern regions of the temperate climatic regions of the world, where environmental stresses were minimal (Andrews, 1982). Even in these traditional areas, where an infrastructure for seed production exists, seed quality in soybeans has been a problem. In nearly every year, soybean seed production fails in some particular areas due to adverse climatic conditions. In these cases, soybean seed is brought from areas with good production to the short-supply areas, generally along east-west lines (Delouche, 1975).

With the increased demand for soybean products, the crop expanded rapidly into the warmer, humid areas and recently into tropical areas (Andrews, 1982). A major constraint to expansion of tropical soybean production is the lack of adequate seed (Greg, 1982). High temperatures and relative humidities in tropical and subtropical environments make the production of quality soybean seed and the maintenance of seed vigor during storage difficult (Delouche et al., 1973; Minor and Paschal, 1982; Delouche, 1982; Dassou and Kueneman, 1984; Camacho and Múnera, 1986; Singh et al., 1988).

Adverse effects of storage fungi, mainly *Aspergillus* and *Penicillium* species (Christensen and Kaufmann, 1969; Christensen and Meronuck, 1986; McGee, et al., 1987; Henning, 1988), together with physiological deterioration are major causes of decay and loss of germination. Soybean seeds deteriorate rapidly under conditions of high moisture (Matthes et al., 1969; Delouche, 1973; Delouche, 1982; West et al., 1985). Harrington (1959) suggested that high moisture was the greatest single cause of loss of viability and vigor in seed. In his classical "thumb rules of drying seed," Harrington (1960) illustrated the damaging effects of moisture and temperature on seed germination. The storage life of seeds is doubled for each 10°F decrease in temperature or for each 1% decrease in moisture content. According to Roberts (1986), this implies that there is no interaction between moisture and temperature. These rules remain true and are supported by research within the region of normal ambient conditions, but not in experiments including a wide range of temperature (3 to 90°C) and from 6 to 25% moisture content (Roberts, 1986). Under those circumstances, the

relationships between moisture and temperature would not be linear as the rules imply.

To maintain viability and vigor, seeds must be dried to an adequate moisture content and stored under conditions of temperature and humidity that prevent rehydration (Matthes et al., 1969). Seed is often too high in moisture for storage when harvested. Drying of seed is a critical operation in any location, but especially in the humid tropics and subtropics.

Seeds are hygroscopic (Matthes et al., 1969) so that their moisture content is in equilibrium with ambient relative humidity. When the humidity is high, seed moisture content is also high; when the RH is low, seed moisture content is low (Delouche, 1973). Matthes and Butler (1968) recommended a storage moisture content of 9-10% for soybean, which would equilibrate with a 55% relative humidity.

Delouche (1975) reported that seed of high initial quality can be safely stored under tropical conditions for nine months at moisture contents of 9.0 to 9.5% (50 to 60% RH) and temperatures of 20 to 25°C. Another alternative would be to dry the seed to 9% or less moisture and then store the seed in vaporproof packages, such as heat-sealed, 10-mil, polyethylene bags (Delouche et al., 1973; Delouche, 1975).

According to Harrington (1959), even sufficiently dry seed in storage may gain moisture to unsafe levels during periods of humid weather. If moisture in seed is higher than 55-60%, then germination takes place. From this moisture range down to 18-20%, respiration is extremely high, both the respiration of the seeds and of microorganisms. Between 12 and 20% seed moisture, mold growth may occur, and the fungi

develop on cracked and damaged seed, especially. In addition, there is an active respiration in seed, which causes rapid loss of vigor and eventual loss in germination. Harrington (1959) further speculated that one explanation of this loss in vigor is that there is enough moisture for respiration which uses food energy present in the cells but there is not enough moisture for movement of energy from food storage tissues to these respiring cells. This would result in local starvation. However, more recently, Vertucci and Leopold (1987) and Leopold and Vertucci (1989) reported that oxidative processes are probable determinants of longevity of seeds in storage since mitochondrial respiration was shown not to occur in soybean seeds below 24% moisture content. They suggested that the additional oxidative processes observed in soybean at low water content between 10 and 24% may contribute to the poor longevity of soybean seed compared to pea [*Pisum sativum* (L.)]. These results are in part supported by the findings of Van Toai et al. (1986), who found that respiration rates did not show the pattern of seed deterioration as indicated by other seed vigor tests. Byrd and Delouche (1971) also reported that respiratory rate (oxygen consumption) was the least efficient index to evaluate seed storability at any interval during storage.

## Seed Deterioration

According to Delouche (1982) and Mills (1986) deterioration is traditionally associated with storage. However, seed deterioration is normally initiated during the period following physiological maturation

(TeKrony et al. 1987; Delouche, 1975), which may be considered the first phase of the storage process.

The extent of field deterioration of seeds establishes their basic quality. During harvest and later operations, seed quality can only be maintained, not improved (Delouche, 1982).

Soybean seed quality can be reduced by many factors such as environmental stresses (moisture, temperature, diseases, and insects) during the post-maturation pre-harvest period (Andrews, 1982; França Neto, 1989) or during storage (Andrews, 1970).

The performance potential of a seed is progressively impaired through deteriorative processes which inevitably occur over time. Very little is known about the exact mechanism or mechanisms of seed deterioration. Most likely during deterioration, essential systems and mechanisms are progressively impaired so that the future or potential of the seed in terms of germination and subsequent growth and development of the seedling become progressively more serious.

The nature of the aging process in a desiccated system differs significantly from the forms of deterioration encountered in physiologically active organisms (Priestley, 1986). Seed viability and vigor depend on the integrity of cellular macromolecules and the orderly compartmentalization of the cell; however, in a dry seed, degradation of these structural and functional elements will progress irreversibly as a result of chemical reactions or other forms of denaturation.

Membrane degradation and loss of control of permeability occur during the early stages of seed deterioration (Bewley, 1986). Energy-yielding and biosynthetic processes are then affected, which results in

decreased rates of respiration, reduced mobilization of food reserves to the embryonic axis, and decreased germination and early seedling emergence. When deterioration occurs, the seed is more susceptible to environmental stresses and seed-rotting microorganisms. Later, as deterioration progresses, the seed fails to emerge in the field and finally even in the ideal environment of the germinator (Delouche, 1973).

Deterioration of seed is considered by Delouche (1982) as inexorable (as for all living systems). Theoretically, deterioration cannot be prevented, but its rate can be controlled by manipulating the primary factors (temperature and moisture) and thus the seed can maintain viability for many years. Recently, considerable attention has been given to the possibility that the deleterious effects of aging during storage could be reversed or ameliorated if seeds were soaked briefly and then allowed to dry (Priestley, 1986). This "priming" treatment has been shown to accelerate the germination of certain types of seeds (Heydecker et al., 1975), extend their longevity in storage, and reduce leakage of partially deteriorated soybeans (Tilden and West, 1985). The repair mechanism is still debated; some workers believe that the benefits are more physical than metabolic, as free radicals are removed. Priestley et al. (1985) found that moderate hydration of the soybean embryonic axis followed by drying led to a small decrease in organic, free radicals compared to untreated material. A possible cellular-repair mechanism is also suggested (Priestley, 1986).

Soybean seeds are inherently short-lived (Delouche et al., 1973) as they deteriorate faster than many other seed crops, except shelled

peanuts. Justice and Bass (1978) classified soybeans in the "least storable" group in their "relative storability index." The storability of seed is very much influenced by the degree to which the seed has deteriorated prior to storage (Delouche, 1975). However, in the humid tropics, Minor and Paschal (1982) showed that even high seed quality will not confer an adequate storage life for soybean.

## Deterioration of Stored Seeds

The effect of storage containers, environment of storage (open and conditioned), and moisture contents of the seeds that enter storage has been extensively studied. Warham (1986a, 1986b) compared packing materials for seed with particular reference to humid tropical environments and evaluated their effects on moisture uptake by dry wheat seeds. Moisture uptake by wheat seed within relatively impermeable sacks was directly related to the water vapor transmission rate (WVTR). The least permeable were polyvinyl chloride, polyethylene-coated kraft paper, and low-density polyethylene. Jute, Kraft paper, and woven polypropylene had no effect on the water uptake by the seeds.

These results are supported by França Neto et al. (1984), who reported no significant differences in moisture content of seeds stored in jute, multiwall paper bags, and woven polypropylene. Germination was only slightly decreased throughout the six-month storage period. However, seed vigor, as determined by the accelerated aging method (42°C for 48 h), was significantly reduced with storage in three types of packing material in Londrina (subtropical) and Ponta Grossa (temperate).

Amaral and Baudet (1983) studied the effect of open storage on soybean seeds with two initial moisture contents (11.4 and 13.4%) in three different kinds of packages. No significant differences in moisture content and standard germination were found between moisture levels and among packing materials. However, seed vigor, as measured by the accelerated aging test (42°C for 72 h), was drastically reduced in all treatments after five months of storage. The seed moisture fluctuated according to the relative humidity of the air independently of the packing material (jute, polyethylene, and multiwall paper bags).

Similar results were reported by Singh et al. (1988) in India. Seed germination was reduced with time of storage from January to July. The type of container (gunny bags, cloth bags, HPD fertilizer bags, and thin containers) had no significant effect on seed viability. Germination was maintained only in fungicide-treated seeds.

M-Hatan and Jamro (1989) in Pakistan stored soybean seeds in cloth bags, gunny bags, polyethylene bags, pitchers, tincans, pods (at room temperature), and pods in a refrigerator at 6°C for 32 weeks. The initial moisture content of the seed was 14.5%. As expected, because of the high initial moisture, storage in an air-tight container was more detrimental to seed quality than any other treatment. Germination and vigor gradually decreased in all treatments during the storage period.

Henning et al. (1985) compared the effect of two initial levels of seed moisture and storage environment on seed quality of 'Tropical' soybean seeds produced and stored in the tropical region of Brazil. Seed vigor and germination, determined by accelerated aging, the tetrazolium (2,3,5 triphenyl tetrazolium chloride) test, and the

standard germination test, significantly decreased after 45 days in open storage. After three months, the incidence of *Aspergillus* spp. was high (above 50%) and the standard germination and vigor (accelerated aging) were drastically reduced, independently of their initial moisture level. On the other hand, seeds stored at 12-15°C and 65-70% RH showed little decrease in quality after six months. The occurrence of *Aspergillus* spp. (storage mold) was nearly zero, as determined by the blotter test.

Breeding Efforts to Improve Seed Quality in Field and Storage

Field performance of soybeans is frequently poor in the tropical areas mainly because of deterioration in ambient storage. Controlled temperature and relative humidity for adequate seed storage, when available (Matthes, et al. 1969), is not economically feasible for most farmers in developing countries (Camacho and Múnera, 1986). For this reason, there is a renewed interest to identify genotypes with resistance to field weathering and with better storability.

Russom (1983), in Nigeria, studied the effect of storing period and type of storage on seed germination of American, Indonesian soybean lines, and their crosses. After nine months of open storage, germination of American lines had dropped to 18% as compared to 82% of Indonesian lines. American x Indonesian crosses had intermediate viability (42%), therefore the seed storability of the high-yielding American lines could be improved by backcrossing with Indonesian lines.

Van Toai et al. (1986) tested five cultivars, fungicide seed treatment, and storage environment on carry-over soybean seed quality. A range of storability was reported among the five cultivars from

different maturity groups. 'Cutler 71' of maturity group IV was the best and 'Amsoy 71' of maturity group II was the worst. The fungicide treatment became significantly different only after 24 months of storage in the warehouse, the least favorable storage environment.

Dassou and Kueneman (1984) used an incubator weathering treatment of 30°C at 95% RH for seven days. They identified nine genotypes with resistance to weathering and to deterioration in storage. Large-seeded genotypes were generally susceptible to field weathering and deterioration in storage. Some small-seeded genotypes were resistant; others were susceptible. Black-seeded genotypes were more resistant to incubator weathering than yellow-seeded genotypes. Similar results were previously reported by Starzinger et al. (1982) and later by Yaklich and Kulik (1987).

In subsequent work, Kueneman and Costa (1987) evaluated four brazilian cultivars with colored-seeded mutants to assess the role of seed color on seed deterioration in similar genetic backgrounds. With the same incubator-weathering system, the authors reported significantly better seed quality for all colored-seeded isolines. However, the reasons why colored-seeded soybeans frequently have superior seed longevity remains to be elucidated.

Another trait that has been pursued by soybean breeders to improve seed quality under adverse environmental conditions is the presence of an impermeable seed coat. Impermeable seed coats may inhibit or retard imbibition of water in seeds of other crops, such as cotton [*Gossypium hirsutum* (L.)] (Patil and Andrews, 1985) and snap bean [*Phaseolus vulgaris* (L.)] (Taylor and Dickson, 1987; and Holubowicz, et al., 1988).

The impermeable seed coat characteristic improves seed quality in snap beans by reducing chilling injury (Taylor and Dickson, 1987) and extends the storage life of cotton seed (Patil and Andrews, 1985).

Soybean seed quality in humid environments is related to the amount of water that the mature seed imbibe before harvest and during storage (Calero, et al., 1981). A negative correlation between seed size and water uptake was found in some materials (Hill et al., 1986b). The presence of elongated pores and a high density of waxy material imbedded in the epidermis were associated with low absorption.

Seed coat impermeability has been reported to improve seed viability under adverse weather conditions (Hartwig and Potts, 1987) and to confer better storability under simulated tropical conditions (Minor and Paschal, 1982) as well as artificial weathering in an incubator (Yaklich and Kulik, 1987). Hardseededness reduced the incidence of seedborne *Phomopsis* spp. (Hill et al., 1985). Yaklich and Kulik (1987) reported significantly less infection by *Phomopsis phaseoli* in a cultivar with a black, impermeable seed coat. They implied that an impermeable seed coat is an effective barrier to the penetration by *P. phaseoli*, and consequently the impermeable seed coat prevents seed decay.

However, despite all reports that seed coat impermeability can result in better seed quality, there are some undesirable characteristics that may restrict its use to solve problems of poor seed quality in warmer areas. The expression of this character is governed by at least three genes and thus it is influenced by several factors. Post-harvest drying temperature (Potts et al., 1978), water stress

during seed formation (Hill et al.,1986b), seed size (Hill et al., 1986a), and the field environment (Minor and Paschal, 1982; Hartwig and Potts, 1987) are all reported to have marked effects on hardseededness.

## Synthetic Seed Coats

Although seedcoat impermeability is promising and highly desirable, it is unlikely that a soybean breeding program for warm and humid areas could depend entirely upon this character to improve seed quality and storability. The impermeability of seed coats is so dependent on the environment, and, consequently, it is unpredictable. New and safer methods must be developed in the meantime. Since storage does not end until the seed is actually planted in the field (Delouche et al., 1973), the application of synthetic seed coats to prevent moisture uptake from the environment would be a desirable alternative. The seed would be protected during all phases of the storage process after harvest, i.e., the distribution of the seed to the market place, transport, and then in the farmer's storage until the time the seeds are actually planted.

Research on synthetic seed coats, pelletization, and seed encapsulation are recent technologies that have been developed mainly to deliver fungicides, insecticides, herbicide safeners (Rushing, 1986), or biocontrol agents (Lutchmeah and Cooke, 1985).

Halmer (1986) reported a new technique that is commercially available in Europe to apply precise doses of pesticides or additives to seeds. These chemicals are formulated with a polymeric binder and sprayed onto a fluidized suspension of seeds in warm air. The materials

dry in contact with the seed coat, forming an even, colored, water-permeable layer of less than 5% of the seed weight. Continuous-input equipment is used to coat bulk crops such as peas [*Pisum sativum* (L.)] at a rate of two tons $h^{-1}$.

Synthetic seeds (encapsulated embryos) of alfalfa [*Medicago sativa* (L.)] have been produced in California (Redenbaugh, 1986). A protective polymer covering [Elvax® DuPont (ethylene, vinylacetate acrylic acid terpolymer)] was reported to be adequate to protect the sodium alginate (gel matrix) and to retard desiccation. Krylov and Reshetnikov (1985) reported increased field emergence, plant population (+20%), and yield of soybeans in Western Siberia when seeds were pelleted with a polymer film containing fenthiuram (thiram + BHC + copper trichlorphenate).

In peanuts, seed encapsulation with nitrocellulose or ethyl cellulose has been reported to have some profound effects on the mobilization of reserve material during seed germination. General increase in activity of lipase, α-amylase, and invertase were observed. On the other hand, the activity of protease decreased during the early stages of germination (Wadhwa et al., 1988).

Baxter and Waters (1986) determined the effect of a hydrophilic polymer Waterlock B100 on the imbibition, respiration, and germination of sweet corn [*Zea mays* (L.) var. *saccharum*] in soils with varying water potentials. Coated seeds had a higher final percentage of imbibition, higher rates of respiration, and germination in soil at water matric potentials of -0.01 and -0.40, than non-coated seeds. As the water potential decreased, seed coating was reported to have a deleterious effect on the physiological processes leading to germination.

Most of the research developed on seed coating with polymers was to deliver chemicals or to protect the seed in the soil under adverse conditions. West et al. (1985) were the pioneers to test polymers as moisture barriers to maintain soybean seed quality stored in ambient conditions with high humidity.

As previously mentioned, soybean seeds deteriorate rapidly under conditions of high moisture (Matthes et al., 1969; Delouche, 1982; West et al., 1985). Synthetic coats that restrict water uptake (West et al., 1985) could possibly prevent deterioration. They tested several different polymers. Daran® 220 [poly(vinylidene chloride)] reduced water uptake in an atmosphere of 100% relative humidity, but the chemical increased water uptake in standard germination conditions. Coated seeds resisted the stress caused by accelerated aging and showed less fungal growth than non-coated seeds. Unfortunately, the effects of the polymer coating on water uptake in long-term storage, such as the time required from harvest to planting, was not studied.

McGee et al. (1987) evaluated the factors that influenced the efficacy of moisture barriers alone and in combination with the fungicide thiabendazole to control the invasion of storage fungi in maize and soybean seeds. Maize seeds coated with Daran® 220 had a reduced rate of moisture uptake during three months in an atmosphere of 85% relative humidity. Coated and non-coated seeds were invaded by storage fungi to the same degree and germination was greatly reduced. Thiabendazole controlled the invasion of storage fungi and resulted in better germination. Soybean seeds were coated with Daran® 220 and Daran® 8600 either alone or in combination with thiabendazole. These

chemicals were applied with a Gustafson Batch Laboratory Treater or a Vector/Freund Hi-Coater® designed to coat pharmaceutical tablets. Germination was greatly reduced after seeds were encapsulated using the Vector/Freund Hi-Coater®. The rate of moisture uptake in an atmosphere of 85% RH was also reduced. However, practical information on the benefits or problems of these coating techniques on seed quality during prolonged storage was not presented. Only a short storage time of three months for maize and two months for soybean were evaluated.

To summarize the pertinent literature, soybean seeds deteriorate rapidly in high temperature and relative humidities, certain polymers applied in various ways may reduce the rate of deterioration, and no long-term studies to determine the effect of synthetic seed coats on viability have been done.

The objectives of this study were to i) screen materials adequate for seed coating, ii) test different methods of application of polymers, and iii) evaluate the effects of the synthetic coatings on the physiological and pathological quality of soybean seeds stored under ideal and adverse storage conditions.

## MATERIALS AND METHODS

### Experiment I

After preliminary tests (Appendix A) developed to identify suitable coating materials and application methods, two polymer formulations (polyvinylidene chloride copolymer emulsions), Daran® 220 and Daran® 8600 were used to coat 'Century-84' soybean seeds. These polymers are manufactured by W. R. Grace and Company, Lexington, MA. Additionally, a fungicide, Mertect®340F (thiabendazole), was included in each coating treatment.

Coatings were applied in a Vector/Freund Hi-Coater®, Model HCl00 by Vector Corporation (Bexco International) in Cedar Rapids, IA. The machine was originally designed to coat pharmaceutical tablets. In this machine, seeds were turned in a rotating drum through which air was passed at controlled humidity and temperature. The temperature of air was adjusted to below 45°C so that the seed bed temperature was kept around 40°C. Both polymers were applied at the rate of 50 g $kg^{-1}$ seed and the fungicide thiabendazole was applied at 20 ppm through air-atomization spray guns. In one treatment, talcum powder was added to the Daran® 8600, to prevent agglomeration of the seed that could possibly damage the coating when the seeds break apart.

The experimental design was a randomized complete block design with three replications. Treatments were a factorial arrangement of

coatings (three), fungicides (two), and time of storage (five). The data were analyzed by the PROC GLM and PROC ANOVA procedures of SAS (Statistical Analysis Systems).

Storage Condition

Approximately one kilogram of seed from each treatment was placed in plastic boxes (three boxes per treatment) and kept in simulated tropical conditions (STC) at 85% RH and 25°C. Three germination carts, each one representing one block, were maintained at 85% RH by using glycerol:water solution (690 ml : 1810 ml). Five trays containing one Kimpack germination pad each were soaked with 500 ml of the above solution and inserted in five equidistant shelves in each cart. The carts were hermetically closed and kept at 25°C in the germination room of the Seed Science Center. Temperature and relative humidity were monitored throughout the experiment with hygrothermographs. A second set of samples from the same treatments was kept in paper bags in the seed storage facility at 10°C and 50% RH.

Sampling and Tests

Periodically, seed samples from both environments (50% RH and 10°C and 85% RH and 25°C) were drawn. Moisture content of the seeds was measured monthly by oven drying at 103°C for 24 h and later corrected to 103°C for 96 h. Seed quality was evaluated before storage (time zero) and afterwards every other month. The following tests were performed on the seed samples.

Standard Germination

Four replications of 100 seeds were planted on two layers of premoistened (800 ml of water) Kimpack paper and germinated in a germination chamber at 25°C under an alternate light-exposure regime. After seven days, the evaluation was performed according to the Rules for Testing Seeds (Association of Official Seed Analysts - AOSA, 1981).

Invasion of Storage Fungi

Fifty seeds per replication were surface sterilized in a 1.05% sodium hypochlorite solution (Clorox® 20%) for one minute, rinsed in sterile distilled water, and incubated on malt-salt agar (MSA) for 14 days at 25°C.

Tetrazolium (TZ) Test

Tetrazolium tests were performed according to procedures described by Delouche et al. (1962), Moore (1973), and as modified by França Neto et al. (1985). Two replicates of 50 seeds each were used per sample. Seeds were preconditioned in moist paper toweling overnight for 16 hours at room temperature (± 23°C). The seeds were then placed in 50 ml beakers and covered with 0.075% solution of 2,3,5-triphenyl tetrazolium chloride, and incubated at 37°C for 3.5 hours. After the incubation period, the seeds were rinsed throughly with cool, running tap water, and left immersed in water until evaluations were made. Seeds were evaluated for germination, vigor potential, and levels of mechanical damage, deterioration (storage), and stink bug damage. The occurrence of hard (impermeable seeds) was also recorded, since hard seed was a

major problem when the seeds were coated with the polymers especially before storage or when they were kept at 50% RH at 10°C.

Emergence in Greenhouse

To compare the effects of the two environments of storage on the integrity of the coating, seeds that had been stored for seven months at 50% RH at 10°C were sampled and stored for two additional months at 85% RH at 25°C. Their emergence was compared to seeds kept for nine months at 50% RH at 10°C. Each experimental unit was composed of three trays filled with a sterilized 4:1 mixture of soil and sand. One hundred seeds were planted in each tray and the number of emerged seedlings were counted after 7 and 14 days.

Field Emergence

A field experiment was planted in July 1987 on the Curtiss Farm (ISU) in Ames, IA. Plots were 5.3 m long and 3.3 m wide. Four rows of 100 seeds were mechanically planted in each plot. A randomized complete block design with six replications per treatment was used, and the final stand count was made 28 days after planting.

Experiment II

To study the effectiveness of the polymeric coatings in maintaining seed quality and to follow the deterioration processes by different testing techniques, a new experiment was designed at the University of Florida. Samples of 'Century-84' soybean seeds coated with Daran® 8600 or Daran® 8600 + TBZ + talcum powder in Cedar Rapids, IA, were brought to the Agronomy Seed Lab (UF) for further studies. A new treatment, Daran® 8600 at $\leq$ 20 g $kg^{-1}$ seed was added. In this treatment, the polymer was applied by placing the seed in an open chamber, adding enough polymer with deionized water as the carrier to cover the seed. The chamber was rotated gently to assure complete contact and to remove entrapped air. Exposure of seed to the polymer was less than 30 sec. The polymer solution consisted of 50% polymer and 50% water (v/v). The seeds were separated from the solution by passing the mixture through a screen. Drying was accomplished by two fans blowing air over the coated seed placed on metal foil. Manual separation of the seed prevented agglomeration. This method was similar to the one used by West et al. in 1985.

Since there was no effect of the fungicide treatment in previous studies, it was not included in this study. In this experiment the effect of the polymeric coatings over the time of storage at 85% RH at 25°C (STC) was investigated. Coated and non-coated seeds were viewed through a Hitachi S-450 scanning electron microscope, operated at 20 kv, and images were recorded with Polaroid® type 55 P/N 4 x 5 land film.

A randomized complete block design with four replicates (shelves) and a factorial arrangement of the four coating treatments and five times of storage was used. The data were analyzed by the same procedures described in experiment I.

Storage Condition

Twenty samples of ± 0.5 kg of seed per treatment (eighty samples total) were individually prepared in cheesecloth bags and stored in a chamber at 85% RH at 25°C for periods up to eight months.

The 85% RH was obtained by inserting four trays with 3.0 L of deionized water on the bottom shelf of the chamber and the surface of evaporation was decreased or increased according to the needs. Temperature and relative humidity were constantly monitored by a hygrothermograph.

Sampling and Tests

Evaluations were made before and during the storage period. Moisture content was measured at monthly intervals by oven drying the seed at 105°C for 96 h. Seed quality tests were performed every other month, as described.

Standard Germination

Four replications of 50 seed each were placed in rolled paper towelling and stored at 25°C for seven days. Evaluation was performed according to procedures outlined for soybeans in the Rules for Testing

Seeds (Association of Official Association Seed Analysts - AOSA, 1981).

Emergence in Sand

Two replicates of 100 seeds each were used for each experimental unit. Seeds were planted in a 10 x 23 x 30 cm plastic tray containing 3.0 L of washed, air-dried sand. The planting depth was 3.0 cm and approximately 450 ml of water were added to each tray after planting. Additional water was added as necessary to keep the sand moist. Trays were kept at 25°C under alternate light and dark. The number of emerged seedlings were counted 10 days after planting. Seedlings were evaluated according to the Rules for Testing Seeds (AOSA, 1981).

Blotter Test

Invasion of seed by storage fungi and other microorganisms was evaluated through the blotter test as described by Neergaard (1977). Seeds were placed directly on two layers of germination paper moistened with 18 ml of deionized water in 14.0 cm diameter plastic Petri dishes. Five dishes containing 20 seeds each were used per replication. After the incubation period of seven days at 25°C under eight hours of light (daylight fluorescent), the percentage of seeds infected with *Aspergillus* spp., *Penicillium* sp., *Bacillus* sp., and other bacteria and fungi was recorded.

Tetrazolium (tz) Tests

Two replicates of 50 seeds each were used per sample and evaluations were performed as described in experiment I, with little modification.

The incubation conditions were 41°C for 2.5 hours instead of 37°C for 3.5 hours.

Experiment III

The experimental plan used in this study included a new cultivar, two different moisture contents of the seeds and only one polymer formulation with the addition of talcum powder.

Seed Source

Two bushels of 'Tracy-M' foundation seed produced in 1988 at Mississippi Agricultural and Forestry Experiment Station, Mississippi State University, MS were used in this study. Seeds were received in December, 1988 and submitted to the tetrazolium and blotter tests to determine physiological and pathological quality prior to other treatments. The vigor potential of the seed was 91% and germination was 95%. In the blotter test *Cercospora kikuchii* (Matsu. and Tomoyasu) was the most prevalent pathogen, which was detected in 3.7% of the seeds. *Phomopsis* spp. and *Fusarium semitectum* Berk. (Rev.) were detected in only 0.5% of the seeds. Seed moisture content initially was 94 g $kg^{-1}$ fw. Before coating, half of the sample (± 25 kg seeds) was dried to 57 g $kg^{-1}$ fw. Both samples were shipped to Vector Corporation (Bexco International) at Cedar Rapids, IA for coating with Daran® 8600 at the rate of 30 g $kg^{-1}$ seed. Talcum powder was added to assure coating integrity.

Storage Condition

After the seeds were coated and returned to Florida, 96 seed samples of 0.5 kg each (24 samples per treatment) were prepared in individual cheesecloth bags, each sample represented one experimental

unit (plot). These samples were stored in a chamber at 85% RH at 25°C, as described in the previous experiment, for periods up to seven months.

Treatments

The experiment consisted of a factorial combination of two seed moisture content levels (84 g $kg^{-1}$ fw and 58 g $kg^{-1}$ fw prior to coating), two coatings (Daran 8600® at 30 g $kg^{-1}$ seed and non-coated), and eight times of storage.

Evaluations of seed quality and moisture contents were determined before treatment and monthly throughout the storage, as detailed in experiment II.

The experimental design was a randomized complete block design with three replicates (shelves in the chamber) and the data were analyzed by the same procedures described previously.

## RESULTS AND DISCUSSION

### Experiment I - 'Century-84' Iowa

The moisture content of seeds changed gradually according to the coating treatment and the environment of storage. At 50% RH at 10°C, seeds lost moisture to the surrounding environment (Fig. 1a) whereas, those stored at 85% RH at 25°C gained moisture (Fig. 1b).

The rate at which moisture moved into or out of the seeds was significantly lower ($p \geq 0.01$) for the coating treatments except Daran® 8600 without the talcum addition. All treatments and their interactions were highly significant ($p \geq 0.001$), except in one case for seeds stored at 85% RH at 25°C (Table 1).

The fungicidal treatment itself should have little, if any effect, on the rate of moisture movement into or out of the seeds with their environment. The significance observed ($p \geq 0.001$) is the result of the confounding effects of the addition of talcum powder to seeds coated with Daran® 8600 + thiabendazole (TBZ). Seeds coated with the same polymer without application of talcum powder had a serious problem of agglomeration. When those seeds broke apart, the coating was damaged (Fig. 2). The flaws in the coating were sufficient to allow the seeds to exchange moisture with the environment at rates similar to non-coated seeds.

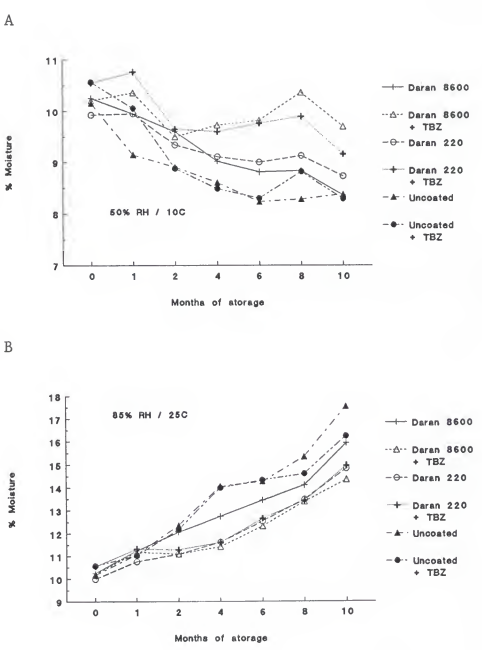


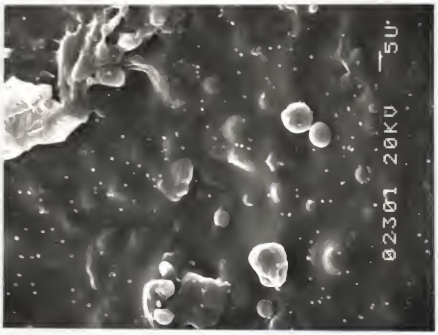

Fig. 1. Moisture content of seeds with several coating treatments under two storage conditions.

Table 1. Analysis of variance for moisture content of seeds with several coating treatments and stored in two environments.

| Source of variation | df | Mean squares | |
|---|---|---|---|
| | | 85% RH / 25°C | 50% RH / 10°C |
| Model | 43 | 9.99 *** | 1.50 *** |
| Block | (2) | 0.17 ns | 0.02 ns |
| Coat | (2) | 18.51 *** | 6.33 *** |
| Fungicide | (1) | 2.71 *** | 7.99 *** |
| Coat*Fungicide | (2) | 2.85 *** | 0.58 *** |
| Time | (6) | 59.84 *** | 5.59 *** |
| Coat*Time | (12) | 1.51 *** | 0.32 *** |
| Fungicide*Time | (6) | 0.77 *** | 0.38 *** |
| Coat*Fung*Time | (12) | 0.17 ns | 0.25 *** |
| Error | 82 | 0.13 | (81)[a] 0.03 |
| C.V. (%) | | 2.90 | 1.80 |

*** Significant at the 0.001 probability level.
[a] Represents the degrees of freedom for the error.

A

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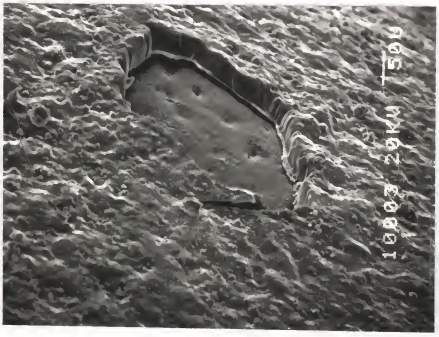


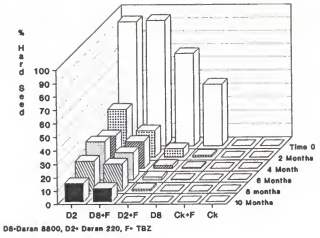

Fig. 2. Scanning electron micrographs showing the surface of seeds coated with Daran® 8600. a) Perfect coating (1,000x) and b) Flaws in the coating when the seeds break apart (170x).

Table 2. Analysis of variance for standard germination test on seeds with several coating treatments, and stored for 10 months at 85% RH and 25°C.

| Source of variation | df | Mean squares | | | |
|---|---|---|---|---|---|
| | | Germination | Abnormal | Dead | Hard |
| Model | 37 | 3787 *** | 609 *** | 4457 *** | 1760 *** |
| Block | (2) | 134 ns | 23 ns | 41 ns | 1 ns |
| Coating | (2) | 6221 *** | 1269 *** | 1671 *** | 6166 *** |
| Fungicide | (1) | 19 ns | 118 ns | 483 ** | 0 ns |
| Coat*Fungicide | (2) | 353 * | 426 *** | 654 *** | 4613 *** |
| Time | (5) | 18797 *** | 2583 *** | 30141 *** | 5574 *** |
| Coat*Time | (10) | 3052 *** | 228 *** | 496 *** | 1420 *** |
| Fungicide*Time | (5) | 48 ns | 116 ** | 135 ns | 76 *** |
| Coat*Fung*Time | (10) | 196 ns | 319 *** | 335 *** | 111 *** |
| Error | 70 | 103 | 32 | 62 | 10 |
| C.V. (%) | | 26.2 | 38.9 | 25.3 | 21.1 |

*,**,*** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

A

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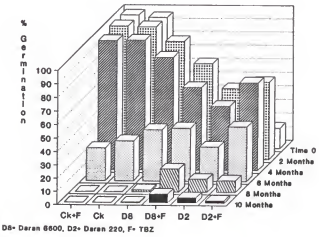



Fig. 3. Effects of polymeric coatings and fungicide treatment on seed quality of 'Century-84' soybean seeds stored at 85% RH 25°C for ten months, as determined by the standard germination test. a) Hard (impermeable) seeds; b) Germination.

In the standard germination test (Table 2), the effect of the coating treatments on the germination and incidence of abnormal, hard, and dead seeds was significant ($p \geq 0.001$). Seed germination was reduced by the coatings when measured before the storage (Fig. 3b). After two months of storage at 85% RH at 25°C, the germination of coated seeds increased; however, the germination remained lower than the non-coated seeds until the fourth month. At six months, germination of coated and non-coated seeds was similar and thereafter the non-coated seeds were all dead (Table 3).

The occurrence of hard (impermeable) seeds was significantly ($p \geq 0.001$) higher in the coating treatments, especially before the storage at 85% RH at 25°C (Fig. 5b). Since the number of hard seeds decreased significantly after two months of storage, the polymeric coating apparently had weakened. One possible explanation is that the synthetic coating allows some transmission of water vapor, as indicated by the observed changes in seed moisture content (Fig 1). The slight increase in the seed volume appeared to be enough to disrupt the physical coating and allow imbibition. This phenomenon has both, positive and negative aspects. One advantage is the seeds may not need mechanical scarification prior to planting. The main disadvantage is that the coating would provide only limited protection to seeds stored under conditions of high relative humidities for several months. Even though the synthetic coating reduced the rate of water uptake from the environment, this would not be enough to protect the seeds from harvest to planting; especially if the moisture content of the seed, when coated, is high ($\geq 100$ g $kg^{-1}$). In this experiment, the seeds were

Table 3. Germination of coated and non-coated seeds stored for ten months at 85% RH and 25°C.

| Coating | Months of storage | | | | | |
|---|---|---|---|---|---|---|
| Treatment | 0 | 2 | 4 | 6 | 8 | 10 |
| | ---------- | ---------- | ---------- | ---------- | ---------- | ---------- |
| Non-coated | 98 A[a] | 98 A | 96 A | 39 A | 0 B | 0 B |
| Daran® 8600 | 8 B | 79 B | 73 B | 33 A | 10 A | 4 A |
| Daran® 220 | 9 B | 55 C | 56 C | 27 A | 9 A | 3 A |

[a] Within each time of storage, means followed by the same letter are not different at the 0.05 level of probability, as determined by the Duncan's test.

coated with moisture content ≥ 100 g $kg^{-1}$. As seed moisture content rose to 140 g $kg^{-1}$ and above, seed viability declined.

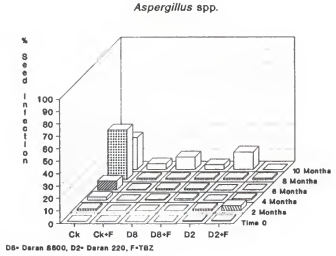
The decrease in viability over time was accompanied by the extensive development of storage molds, especially in the non-coated seeds. *Aspergillus* spp. (Fig. 4a) was significantly reduced ($p \geq 0.01$) by the coating treatments and fungicide application ($p \geq 0.001$). *Penicillium* spp. were not affected by the fungicide ($p \geq 0.36$) but was significantly ($p \geq 0.001$) reduced by the synthetic coatings (Fig. 4b).

Storage under ideal conditions, 50% RH at 10°C, maintained seed quality (Fig. 5a) and had little effect on the polymeric coatings. The percentage of hard seeds (Fig 5b) remained high throughout the experiment, and, consequently germination was significantly lower ($p \geq 0.001$) for the coated seeds (Tables 4 and 5).

The average of the coating treatments over the ten months of storage (Table 5), clearly illustrates the negative effects of the polymeric coats on germination because of the high level of hard (impermeable) seeds.

Seed viability (Fig. 6a) and vigor (Fig. 6b), as evaluated by the tetrazolium test were low for the coated seeds during the first months of storage because lack of imbibition. The percentage of hard seeds was significantly higher ($p \geq 0.001$) for coated seeds. Time was the factor with the largest mean squares (Table 6), since that moisture uptake by the seeds occurred during the storage and affected the integrity of the coating. As a result, seed deterioration progressively increased, as determined by the tetrazolium test (Fig. 6c).

A

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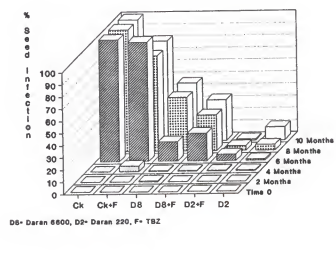
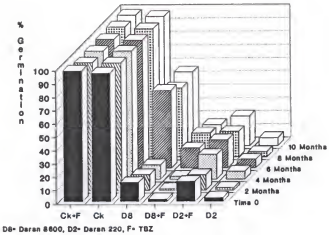



Fig. 4. Incidence of storage fungi on 'Century-84' soybean seeds coated with polymers and treated with fungicide and stored at 85% RH at 25°C, for ten months. a) *Aspergillus* spp.; b) *Penicillium* spp.

A

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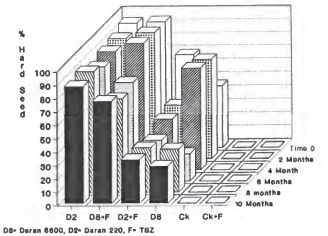
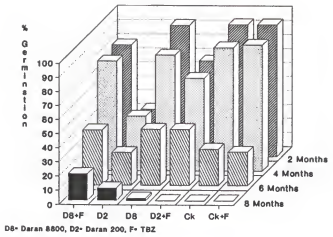



Fig. 5. Effects of polymeric coatings and fungicide treatment on seed quality of 'Century-84' soybean seeds stored at 50% RH at 10°C for ten months, as evaluated by the standard germination test. a) Germination; b) Hard (impermeable) seeds.

A

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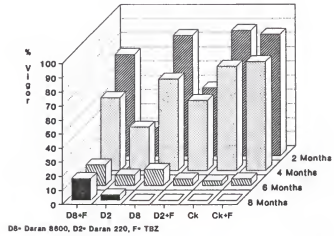



Fig. 6. Effect of polymeric coatings and seed treatment with thiabendazole (TBZ) on several seed quality parameters, as determined by the tetrazolium (TZ) test, during 10 months of storage at 85% RH at 25°C. a) Germination; b) Vigor; c) Deteriorated (non-viable) seeds.

C

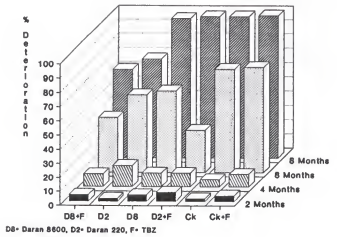



Fig. 6--continued.

Table 4. Analysis of variance for germination and hard seeds, after coating with polymers and fungicide and storage for ten months at 50% RH and 10°C.

| Source of variation | df | Mean squares | |
|---|---|---|---|
| | | Germination | Hard seeds |
| Model | 37 | 4734 *** | 4031 *** |
| Block | (2) | 44 * | 0.3 ns |
| Coating | (2) | 79117 *** | 50668 *** |
| Fungicide | (1) | 338 *** | 336 *** |
| Coat*Fungicide | (2) | 3410 *** | 16908 *** |
| Time | (5) | 675 *** | 947 *** |
| Coat*Time | (10) | 437 *** | 616 *** |
| Fungicide*Time | (5) | 95 *** | 216 *** |
| Coat*Fung*Time | (10) | 146 *** | 167 *** |
| Error | 70 | 11 | 19 |
| C.V. (%) | | 7.7 | 10.0 |

*,**,*** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 5. Effect of polymeric coatings on the germination and incidence of hard (non-imbibed) seeds, stored at 50% RH and 10°C, for ten months.

| Coating treatment[a] | Germination | Hard seed |
|---|---|---|
| | ----------%---------- | |
| Non-coated | 97 A[b] | 0 B |
| Daran® 8600 | 22 B | 65 A |
| Daran® 220 | 11 C | 65 A |

[a] Average of treated and untreated seeds with fungicide (TBZ).

[b] Within each column means with the same letter are not significantly different at the 0.05 probability level, as determined by the Duncan's test.

Table 6. Analysis of variance for germination, vigor, deterioration, and occurrence of hard seeds, coated polymers and fungicide, after storage for 10 months at 85% RH and 25°C.

| Sources of variation | df | Mean squares | | | |
|---|---|---|---|---|---|
| | | Germination | Vigor | Deterioration | Hardseed |
| Model | 25 | 3253 *** | 3000 *** | 3779 *** | 739 *** |
| Block | (2) | 53 ns | 3 ns | 61 ns | 1 ns |
| Coat | (2) | 2710 *** | 2906 *** | 814 *** | 4844 *** |
| Fungicide | (1) | 572 * | 207 ** | 227 ns | 1 ns |
| Coat*Fungicide | (2) | 634 ** | 318 *** | 476 ** | 1956 *** |
| Time | (3) | 21736 *** | 19541 *** | 28292 *** | 308 *** |
| Coat*Time | (6) | 1061 *** | 1312 *** | 503 *** | 410 *** |
| Fungicide*Time | (3) | 26 ns | 2 ns | 236 * | 229 *** |
| Coat*Fung*Time | (6) | 385 ** | 305 *** | 494 *** | 135 *** |
| Error | 46 | 93 | 28 | 80 | 17 |
| C.V. (%) | | 20.5 | 15.4 | 22.8 | 32.7 |

*,**,*** Significant at the 0.05, 0.01, and, 0.001 probability levels, respectively.

Table 7. Analysis of variance for emergence in greenhouse, of seeds coated with polymers and fungicide and stored in two different environments.

| Source of variation | df | Mean squares |
|---|---|---|
| Model | 13 | 558 *** |
| Block | (2) | 7 ns |
| Coat | (2) | 1062 *** |
| Fungicide | (1) | 13 ns |
| Coat*Fungicide | (2) | 1655 *** |
| Environment | (1) | 648 *** |
| Coat*Environment | (2) | 244 *** |
| Fungicide* Environment | (1) | 100 ** |
| Coat*Fungicide* Environ. | (2) | 280 *** |
| Error | 22 | 8.5 |
| C.V. (%) | | 3.3 |

**,*** Significant at the 0.01 and 0.001 probability levels, respectively.

Emergence in greenhouse (Fig. 7) was used to determine the effects of the two storage environments, fungicide, and polymeric coatings on seed viability. Both seed coating and environment of storage were highly significant ($p \geq 0.001$) and contributed for the largest sum of squares (Table 7). The fungicide treatment had no effect on seedling emergence ($p=0.23$). On the average, non-coated seeds had the highest seedling emergence (98.1%). Seeds coated with Daran® 8600 and Daran® 220 emerged 82.6 and 81.1%, respectively and were not different from each other ($LSD_{0.05}$= 2.48).

Field emergence (Fig. 8) was significantly lower ($p \geq 0.001$) for the coating treatments. Daran® 220 had the lowest emergence (only 26%) followed by Daran® 8600 (63.5%) and non-coated seeds with 90% emergence. The three coating treatments were statistically different from each other ($LSD_{0.05}$= 4.95%).

The largest mean square values (Table 8) were obtained for the coating. The effect of the fungicide, although significant at ($p \geq 0.01$) may be considered as the confounding effect of the addition of talcum powder to Daran® 8600 with fungicide, as previously discussed.

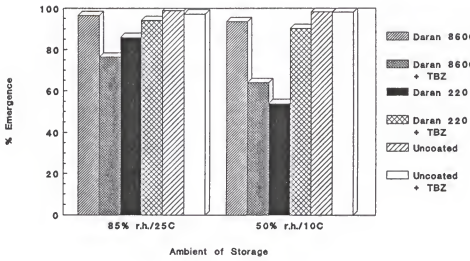



Fig. 7. Effect of two storage environments, polymeric coatings, and thiabendazole (TBZ) on emergence in greenhouse, of 'Century-84' soybean seeds.

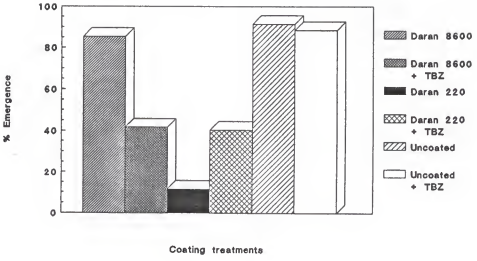



Fig. 8. Field emergence of 'Century-84' soybean seeds after coating with polymers and treatment with thiabendazole (TBZ).

Table 8. Analysis of variance for the field emergence of seeds coated with different polymers and fungicide.

| Source of variation | df | Mean squares |
|---|---|---|
| Model | 10 | 3341 *** |
| Block | (5) | 76 ns |
| Coating | (2) | 12409 *** |
| Fungicide | (1) | 324 ** |
| Coating*Fungicide | (2) | 3944 *** |
| Error | 25 | 35 |
| C.V. (%) | | 9.8 |

**,*** Significant at the 0.01 and 0.001 probability levels, respectively.

Experiment II - 'Century-84' - Florida

In this study, the effects of only one polymer, Daran® 8600, either applied in a Vector Freund Hi-Coater® at the rate of 50 g polymer $kg^{-1}$ seed or manually at c.a. 20 g $kg^{-1}$ seed, were investigated.

Non-coated seeds or seeds coated with the polymer without the addition of talcum powder, rapidly absorbed moisture from the environment (Fig. 9). Daran® 8600 plus talcum powder reduced the rate of moisture uptake and resulted in lower seed moisture content of the seeds during the storage period of eight months (Table 9). A strong block effect ($p \geq 0.0001$) was observed. This block effect was in fact expected because the sources of moisture, trays containing deionized water, were placed at the bottom of the chamber. Consequently, the lower shelves received the direct impact of the water vapor, and the seeds gained moisture more rapidly then those in the upper shelves. Even though the relative humidity was monitored (hygrothermograph in the middle shelf) and maintained at constant 85%, a moisture gradient was established in the chamber. The standard germination test (Table 10) identifies differences among the coating treatments and time of storage on the parameters evaluated. Seed coating with Daran® 8600 + talcum powder strongly reduced ($p \geq 0.05$) germination before the storage at 85% RH and 25°C (Table 11). Mechanical scarification with sand paper was necessary to break the coating and allow imbibition of the seeds (Table 12). Even with scarification germination was lower ($p \geq 0.05$) for the treatments with coated seeds (Table 11). However, two months of storage were sufficient to break the synthetic coating and increase germination (Fig. 10a).

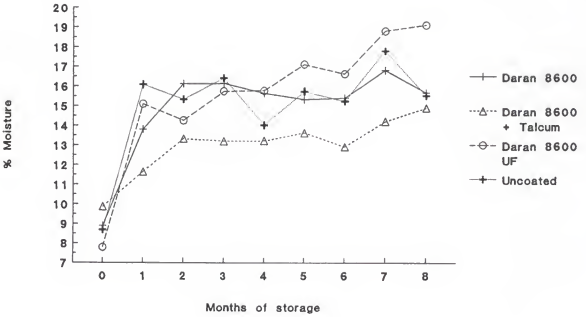



Fig. 9. Moisture content of 'Century-84' seeds coated with Daran® 8600 and stored at 85% RH and 25°C for eight months.

Table 9. Effect of polymeric coatings on the average seed moisture content after eight months of storage at 85% RH and 25°C.

| Coating treatment | Average moisture content |
|---|---|
| | g $kg^{-1}$ |
| Daran® 8600 + Talcum powder | 129.7 A[a] |
| Daran® 8600 | 148.6 B |
| Non-coated | 149.7 B |
| Daran® 8600 UF[b] | 156.1 B |

[a]Within each column, means followed by the same letter are not significantly different at the 0.05 probability level, as determined by the Duncan's test..

[b]UF= Daran® 8600 applied manually at c.a. 20 g $kg^{-1}$ seed.

Table 10. Analysis of variance for the standard germination test on seeds coated with Polymers and stored at 85% RH and 25°C, for eight months.

| Source of Variation | df | Mean squares | | | |
|---|---|---|---|---|---|
| | | Germination | Abnormal[a] | Dead | Hard |
| Model | 22 | 4901 *** | 0.10 *** | 6451 *** | 200 *** |
| Blocks | (3) | 551 *** | 0.04 ns | 971 *** | 7 ns |
| Coating | (3) | 994 *** | 0.09 ** | 5786 *** | 1344 *** |
| Time | (4) | 24128 *** | 0.31 *** | 27354 *** | 1 ns |
| Coating*time | (12) | 600 *** | 0.03 * | 998 *** | 28 *** |
| Error | 57 | 73 | 0.02 | 163 | 3 |
| C.V. (%) | | 21.8 | 55.0 | 27.0 | 37.0 |

[a] Data transformed in arc sin $\sqrt{\%}$

*,**,*** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 11. Effect of polymeric coating and storage time on germination of 'Century-84' seeds coated and stored at 85% RH and 25°C.

| Coating treatment | Months of Storage | | | | |
|---|---|---|---|---|---|
| | 0[a] | 2 | 4 | 6 | 8 |
| | ---------- | ---------- | %---------- | ---------- | ---------- |
| Non-coated | 97 A[b] | 73 ns | 4 C | 0 B | 1 B |
| Daran® 8600 | 88 B | 75 | 20 B | 3 B | 0 B |
| Daran® 8600 + talcum | 82 C | 67 | 51 A | 36 A | 15 A |
| Daran® 8600 UF | 91 B | 80 | 15 BC | 0 B | 0 B |

[a] Seeds were scarified with sand paper prior to planting.

[b] Within each column means with the same letter are not significantly different at the 0.05 probability level, as determined by the Duncan's test.

Table 12. Analysis of variance for scarification of seeds coated with synthetic polymers.

| Source of Variation | df | Mean squares | |
|---|---|---|---|
| | | Germination | Hard seeds |
| Model | 10 | 530.9 *** | 556.2 *** |
| Blocks | (3) | 5.5 ns | 16.3 ns |
| Scarification | (1) | 552.8 *** | 480.5 *** |
| Coating | (3) | 1109.7 *** | 1213.5 *** |
| Scar*Coating | (3) | 470.2 *** | 464.2 *** |
| Error | 21 | 4.8 | 5.8 |
| C.V. (%) | | 2.5 | 29.7 |

[a] Final count 14 days.

*** Significant at the 0.001 probability level.

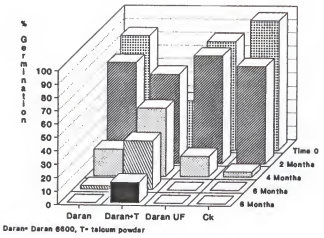
At four months of storage, germination was significantly higher ($p \geq 0.001$) in seeds coated with Daran® 8600 + talcum. After six months, seed viability was near 0% and the incidence of dead seeds increased markedly in all treatments, except Daran® 8600 + talcum (Fig. 10b).

*Penicillium* spp. were the predominant storage microorganisms occurring in the seeds after four months of storage (Fig. 11a). *Aspergillus* spp. (Fig. 11b), *Bacillus* spp. (Fig. 11d) and various other bacteria (Fig. 11c) were also frequent, but at lower levels in seeds coated with Daran® 8600 + talcum (Table 13).

The tetrazolium test was performed on seeds before and during the storage period. To overcome the imbibition problem, coated seeds were mechanically scarified with sand paper prior to conditioning in moist germination towels. This operation caused numerous bruises on the seeds and made the evaluation more difficult. Even with scarification before storage, all coating treatments had a significantly higher number of hard (impermeable) seeds than the non-coated treatments ($p \geq 0.05$) with no difference among the polymer treatments. After two months of storage, only Daran® 8600 + talcum powder treatment high percentage of hard (impermeable) seeds (Fig. 12c).

Seed viability (germination potential) of all the three polymer coatings was lower than the non-coated seeds ($p \geq 0.05$) before storage (Fig. 12a). At two months of storage, there was no difference in germination of coated and non-coated seeds. After four months, seeds coated with Daran® 8600 + talcum powder showed 47.5% germination compared to 10.5% for the non-coated seeds. The other polymer treatments were not different from the non-coated control ($p \geq 0.05$).

A

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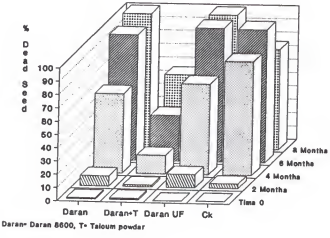
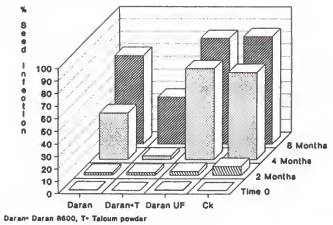



Fig. 10. Effect of synthetic coatings on seed quality of 'Century-84' soybean seeds stored at 85% RH and 25°C for eight months, as evaluated by the standard germination test. a) Germination; b) Dead (non-viable seeds).

A

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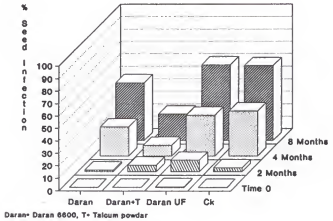
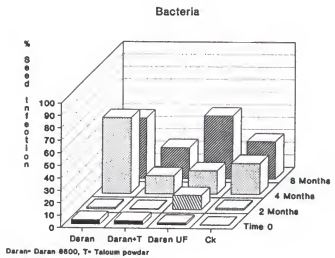



Fig. 11. Incidence of microorganisms on 'Century-84' soybean seeds coated with polymer and stored at 85% RH and 25°C, for eight months. a) *Penicillium* spp.; b) *Aspergillus* spp.; c) Other bacteria; and d) *Bacillus* spp.

C

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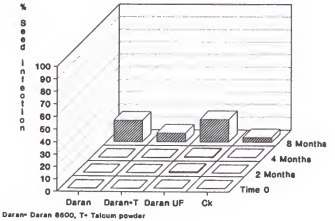



Fig. 11--continued.

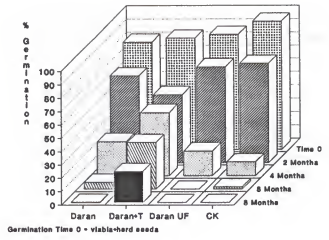
Table 13. Analysis of variance for storage microorganisms occurring in seeds coated with polymers and stored at 85% RH and 25°C, for eight months.

| Source of variation | df | Mean squares[a] | | | |
|---|---|---|---|---|---|
| | | *Penicillium* | *Aspergillus* | Bacteria | *Bacillus* |
| Model | 18 | 0.79 *** | 0.35 ns | 0.29 *** | 0.07 *** |
| Blocks | (3) | 0.23 *** | 0.01 *** | 0.01 ns | 0.01 ns |
| Coating | (3) | 0.50 *** | 0.17 *** | 0.14 *** | 0.03 *** |
| Time | (3) | 3.55 *** | 1.76 *** | 1.28 *** | 0.36 *** |
| Coat*time | (9) | 0.15 *** | 0.05 ** | 0.09 *** | 0.02 *** |
| Error | 44 | 0.028 | 0.014 | 0.019 | 0.004 |
| C.V. (%) | | 34.7 | 32.1 | 36.8 | 75.1 |

[a] Data transformed in arc sin $\sqrt{\%}$.

*,**,*** Significant at the 0.05, 0.01, and 0.001 probability level, respectively.

A

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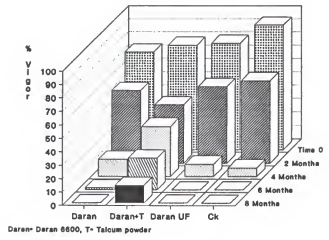



Fig. 12. Effects of seed coating with polymer (Daran® 8600) on several seed quality parameters, as determined by the tetrazolium (TZ) test, during 10 months of storage at 85% RH and 25°C. a) Germination; b) Vigor; c) Hard (impermeable) seeds.

C

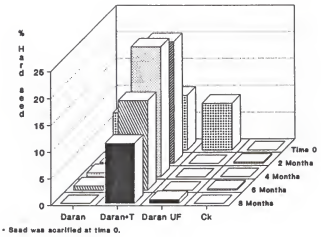



Fig. 12--continued.

After six months of storage, only seeds coated with Daran® 8600 + talcum powder were still viable and germinated 35 and 24% respectively at six and eight months (Fig. 12a). Seed vigor followed the same pattern. Vigor which was initially lower in the coated seeds because of the reduced imbibition, was not different at two months of storage (Fig. 12b). After four months, Daran® 8600 + talcum was consistently superior to the other treatments ($p \geq 0.05$). A significant block effect was also observed for all parameters evaluated by the tetrazolium test, except hard seeds (Table 14).

Emergence in sand was used to simulate field conditions. As for all the other tests, emergence was reduced by the coating treatments when measured before storage (Fig. 13). Similar to germination potential in the tetrazolium test, at two months of storage no difference among the treatments was detected. Thereafter, seeds treated with Daran® 8600 + talcum powder had the best emergence (Table 15). In this test, the significant block effect observed in most of the cases occurred only when the time factor was included in the analysis of variance (Table 16).

Table 14. Analysis of variance for the seed viability, vigor, and occurrence of hard seeds, after coating with polymers and storage at 85% RH and 25°C for eight months.

| Source of Variance | df | Mean squares | | | |
|---|---|---|---|---|---|
| | | Germination | Vigor | Deterioration | Hard seeds |
| Model | 22 | 4232 *** | 3703 *** | 5122 *** | 221 *** |
| Blocks | (3) | 1101 *** | 780 *** | 1462 ** | 5 ns |
| Coating | (3) | 756 *** | 474 ** | 3456 *** | 1247 *** |
| Time | (4) | 20132 *** | 18290 *** | 22436 *** | 37 *** |
| Time*coating | (12) | 624 *** | 395 *** | 707 *** | 73 *** |
| Error | 56 | 119 | 114 | 255 | 7 |
| C.V. (%) | | 28.4 | 33.4 | 30.0 | 50.0 |

*,**,*** Significant at the 0.05, 0.01, and 0.001, probability levels respectively.

Table 15. Effect of polymeric coatings on emergence in sand of 'Century-84' soybean seeds stored for eight months at 85% RH and 25°C.

| Coating Treatment | Months of storage | | | | |
|---|---|---|---|---|---|
| | 0 | 2 | 4 | 6 | 8 |
| Non-coated | 98 A[a] | 70 ns | 1 B | 0 B | 0 B |
| Daran® 8600 | 88 B | 52 | 6 B | 4 B | 0 B |
| Daran® 8600+talcum | 61 D | 50 | 38 A | 36 A | 14 A |
| Daran® 8600 UF | 79 C | 55 | 16 B | 0 B | 0 B |

[a] Within each column, means with the same letter are not significantly different at the 0.05 probability level, as determined by the Duncan's test.

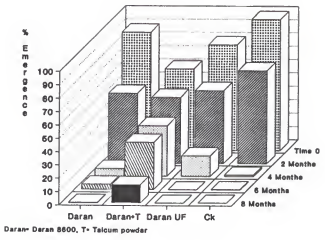



Fig. 13. Emergence in sand of 'Century-84' seeds coated with Daran® 8600 and stored at 85% RH and 25°C for eight months.

Table 16. Analysis of variance for emergence in sand of 'Century-84' soybean seeds coated with polymers and stored for eight months at 85% RH and 25°C.

| Source of Variation | df | Mean squares | |
|---|---|---|---|
| | | Transformed[a] | Untransformed |
| Model | 22 | 0.76 *** | 3.924 *** |
| Blocks | (3) | 0.13 ** | 545 * |
| Coating | (3) | 0.19 *** | 394 ns |
| Time | (4) | 3.32 *** | 18346 *** |
| Time*Coating | (12) | 0.20 *** | 845 *** |
| Error | 56 | 0.03 | 166 |
| C.V. (%) | | 31.4 | 38.9 |

[a] Data transformed in arc sin $\sqrt{\%}$.

Experiment III - 'Tracy-M' - Florida

The results obtained in experiments I and II with 'Century-84' soybean seeds showed very little benefits of the polymeric coatings after six months of storage. In addition, the benefits were not compensated by the initial low imbibition and germination. The causes of the loss of viability could be attributed to either the high moisture contents of the seeds $\geq$10 g $kg^{-1}$, when they were coated, to the amount of polymer applied (50 g $kg^{-1}$), or perhaps to both factors, interacting.

To resolve this problem, in the new experiment designed at the University of Florida, 'Tracy-M' soybean seeds with two different moisture contents were coated with Daran® 8600 at 30 g polymer $kg^{-1}$ of seed, with the addition of talcum powder. Seed quality and moisture content were measured before and throughout the storage, at monthly intervals.

The moisture content of non-coated seeds increased rapidly during the first month of storage at 85% RH and 25°C (Fig. 14). Moisture content increased at a much slower rate in seeds coated with the polymer. Unlike the non-coated seeds that rapidly reached a moisture content of 160 g $kg^{-1}$, after two months of storage, coated seeds showed a constant but slower rate of moisture absorption from the environment. After seven months, coated seeds had 108.5 and 122.2 g $H_2O$ $g^{-1}$ fw whereas non-coated seeds had 157.4 and 161.3 g $kg^{-1}$ for the low and high initial moisture levels, respectively.

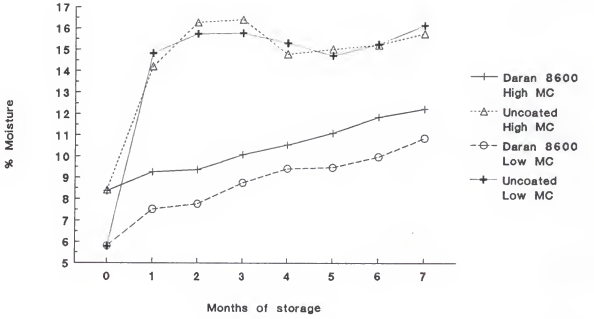



Fig. 14. Effect of polymeric coating on the moisture content 'Tracy-M' seeds, with two initial moisture content levels, during seven months of storage at 85% RH and 25°C.

In a combined analysis of variance (Table 17) including time as a factor, the largest mean squares values were those for the coating treatments, followed by the time of storage. Significant block effects ($p \geq 0.001$) were observed because the moisture stratification conditions of the chamber, as discussed in the previous experiment.

In the standard germination test (Table 17) a significant effect ($p \geq 0.001$) of the polymeric coatings, time of storage, and their interactions was found. No effect of the two initial moisture levels of the seeds on germination was observed except before storage ($p \geq 0.05$), when seeds with a lower moisture level had higher germination. As previously observed (experiments I and II), germination was drastically reduced by the polymeric coatings, when measured before storage at 85% RH and 25°C. Coated seeds germinated only 3 and 18% compared to 96 and 98% in the non-coated controls, for the low and high initial moisture levels, respectively. The occurrence of hard (impermeable seeds) was extremely high before storage (Fig. 15b). After only one month of storage, the percentage of impermeable seeds decreased from 96 and 86% to 15.7 and 16% for the higher and lower initial moisture levels of the seeds. At the same time germination of coated seeds increased to near 80% (Table 18). At two and three months of storage, no differences in germination were observed between coated and non-coated seeds. Significant differences were detected at four months ($p \geq 0.01$) and after five months ($p \geq 0.001$), when coated seeds were the only ones still viable.

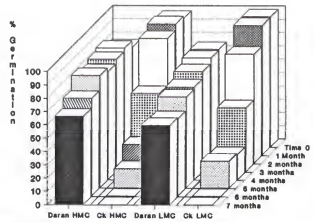
Table 17. Analysis of variance for standard germination test on 'Tracy-M' seeds with two initial moisture content levels, after coating with polymer and storage at 85% RH and 25°C for seven months.

| Source of Variation | df | Mean squares | | | |
|---|---|---|---|---|---|
| | | Germination | Abnormal[a] | Dead[a] | Hard |
| Model | 33 | 3483 *** | 0.020 * | 0.854 *** | 1361 *** |
| Blocks | (2) | 2008 *** | 0.007 ns | 0.513 *** | 2 ns |
| Coating | (1) | 9263 *** | 0.003 ns | 7.978 *** | 13090 *** |
| Moisture | (1) | 518 ns | 0.001 ns | 0.045 ns | 79 *** |
| Coat*Moist | (1) | 68 ns | 0.001 ns | 0.001 ns | 72 *** |
| Time | (7) | 5669 *** | 0.039 *** | 1.942 *** | 2270 *** |
| Coat*Time | (7) | 8565 *** | 0.047 *** | 0.774 *** | 2193 *** |
| Moist*Time | (7) | 173 ns | 0.004 ns | 0.004 ns | 27 *** |
| Coat*Moist*Time | (7) | 94 ns | 0.002 ns | 0.014 ns | 31 *** |
| Error | 62 | 221 | 0.008 | 0.043 | 4 |
| C.V. (%) | | 26.1 | 58.2 | 40.4 | 17.4 |

[a] Data transformed in arc sin $\sqrt{\%}$.

*, *** Significant at the 0.05 and 0.001 probability level, respectively.

A

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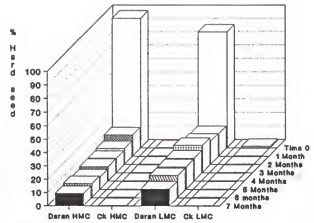



Fig. 15. Effects of synthetic coats and the initial moisture level of the seeds on the quality of 'Tracy-m' seeds during seven months of storage at 85% RH and 25°C. a) Germination; b) Hard (impermeable) seeds; and, c) Dead seeds.

C

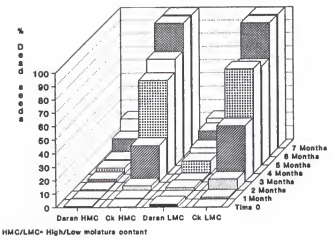



Fig. 15--continued

Table 18. Effect of the time of storage at 85 % RH and 25°C on seed quality of 'Tracy-M' soybean seeds non-coated and coated with polymers.

| Coating | Parameter | Months of Storage | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| | | % | | | | | | | |
| Daran 8600 | Germination | 10.5 | 80.2 | 82.7 | 79.5 | 75.5 | 76.5 | 66.2 | 63.0 |
| Non-coated | | 97.0 | 97.8 | 87.8 | 53.7 | 23.0 | 17.5 | 0.0 | 0.0 |
| $LSD_{(0.05)}$ | | 6.6 | 1.6 | 15.5 | 29.5 | 31.9 | 19.9 | 2.9 | 9.4 |
| Daran® 8600 | Abnormal | 1.2 | 3.5 | 1.7 | 3.3 | 3.3 | 2.2 | 3.5 | 2.5 |
| Non-coated | | 2.2 | 1.3 | 6.3 | 12.2 | 3.5 | 6.3 | 0.0 | 0.0 |
| $LSD_{(0.05)}$ | | 0.8 | 1.9 | 7.9 | 7.2 | 3.7 | 7.8 | 1.4 | 1.1 |
| Daran® 8600 | Dead | 1.5 | 0.5 | 1.3 | 1.7 | 6.8 | 8.5 | 16.2 | 21.8 |
| Non-coated | | 0.2 | 0.8 | 5.8 | 34.2 | 73.5 | 76.2 | 100.0 | 100.0 |
| $LSD_{(0.05)}$ | | 0.8 | 1.8 | 6.8 | 31.5 | 35.4 | 27.1 | 2.7 | 9.2 |
| Daran®8600 | Hard | 90.8 | 15.8 | 14.3 | 15.5 | 13.8 | 12.8 | 13.3 | 11.0 |
| Non-coated | | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| $LSD_{(0.05)}$ | | 2.1 | 1.8 | 4.5 | 2.6 | 2.9 | 2.7 | 2.2 | 3.2 |

As expected, the polymeric coatings always had significantly higher percentage of impermeable seeds compared to the non-coated seeds (Fig. 15b). The occurrence of dead seeds increased markedly in the non-coated seeds after four months, reaching 100% after six months of storage. Coated seeds had only 22% of dead seeds even after seven months at 85% RH and 25°C (Fig. 15c).

The observed increase in dead seeds over time was accompanied by an extensive development of storage fungi (*Aspergillus* spp. and *Penicilllium* spp.), *Bacillus* spp., and other unidentified bacteria (Fig. 16). Significant block effects were observed for *Penicillium* spp. ($p \geq 0.001$) and *Bacillus* spp. ($p \geq 0.01$). The largest mean square values were those for the coating treatments that effectively reduced infection of seeds by microorganisms (Table 19). *Penicillium* spp. were the predominant fungi after four months of storage (Fig. 16a), followed by other unidentified bacteria (Fig.16c) and *Aspergillus* spp. (Fig. 16b). Infection of seeds by *Bacillus* spp., even though common in all treatments after three months of storage, was less than 10% in most cases (Fig. 16d).

The tetrazolium test was not performed on seeds before storage at 85% RH and 25°C, because the coated seeds were highly impermeable to water. Mechanical scarification with sand paper was avoided since it causes extensive damage (bruises) that made the evaluation difficult. In the analysis of variance (Table 20), all of the parameters except initial moisture content of the seed and its interactions, had an effect on seed quality as evaluated by the tetrazolium test.

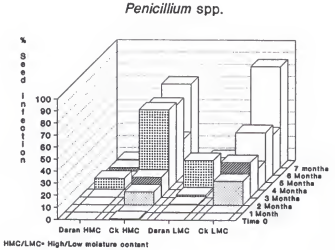
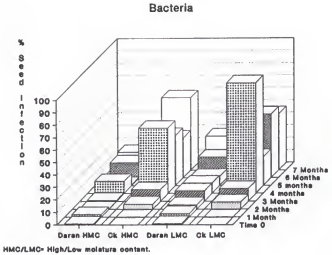



Fig. 16. Incidence of microorganisms on 'Tracy-M' soybean seeds with two initial moisture contents, coated with polymer and stored at 85% RH and 25°C, for periods up to seven months. a) *Penicillium* spp.; b)*Aspergillus* spp. c) Other bacteria; and d) *Bacillus* spp.



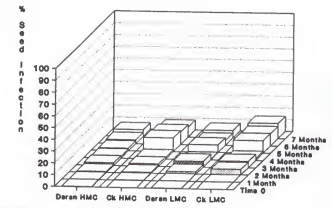




Fig. 16--continued.

Table 19. Analysis of variance for storage microorganisms occurring on 'Tracy-M' soybean seeds coated with polymer and stored at 85% RH and 25°C, for seven months.

| Sources of Variation | df | Mean Squares | | | |
|---|---|---|---|---|---|
| | | *Penicillium* | *Aspergillus* | *Bacillus* | bacteria |
| Model | 33 | 0.339 *** | 0.160 *** | 0.038 *** | 0.300 *** |
| Blocks | (2) | 0.250 *** | 0.005 ns | 0.041 ** | 0.059 ns |
| Coating | (1) | 3.390 *** | 1.458 *** | 0.044 * | 1.073 *** |
| Moisture | (1) | 0.008 ns | 0.005 ns | 0.020 ns | 0.207 * |
| Coat*Moist | (1) | 0.081 ns | 0.033 ns | 0.001 ns | 0.026 ns |
| Time | (7) | 0.665 *** | 0.337 *** | 0.130 *** | 0.846 *** |
| Coat*Time | (7) | 0.251 *** | 0.156 *** | 0.018 ns | 0.281 *** |
| Moist*Time | (7) | 0.043 ns | 0.019 ns | 0.005 ns | 0.024 ns |
| Coat*Moist*Time | (7) | 0.073 * | 0.027 ns | 0.004 ns | 0.064 ns |
| Error | 62 | 0.032 | 0.019 | 0.009 | 0.054 |
| C.V. (%) | | 57.1 | 53.9 | 64.3 | 68.4 |

[a] Data transformed in arc sin $\sqrt{\%}$.

*,**,*** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 20. Analysis of variance for germination, vigor, deterioration, and hard seeds, of 'Tracy-M' soybean seeds coated with polymer and stored at 85% RH and 25°C, for seven months.

| Source of Variation | df | Mean Squares | | | |
|---|---|---|---|---|---|
| | | Germination | Vigor | Deterioration | Hard seeds |
| Model | 29 | 2203 *** | 1718 *** | 3170 *** | 445 *** |
| Blocks | (2) | 3818 *** | 746 ** | 2169 *** | 76 *** |
| Coating | (1) | 6396 *** | 7095 *** | 32019 *** | 11247 *** |
| Moisture | (1) | 217 ns | 129 ns | 119 ns | 27 ns |
| Coat*Moist | (1) | 4 ns | 17 ns | 21 ns | 23 ns |
| Time | (6) | 5089 *** | 4699 *** | 6465 *** | 113 *** |
| Coat*Time | (6) | 3733 *** | 2095 *** | 2686 *** | 94 *** |
| Moist*Time | (6) | 13 ns | 32 ns | 40 ns | 20 ns |
| Coat*Moist*Time | (6) | 73 ns | 22 ns | 49 ns | 18 ns |
| Error | 54 | 237 | 158 | 246 | 15 |
| C.V. (%) | | 34 | 35 | 38 | 32 |

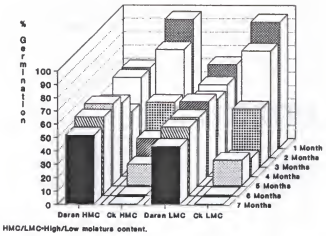
*,**,*** Significant at the 0.05, 0.01 and 0.001 probability levels, respectively.

Coating was the factor with the largest mean square values followed by the time of storage. Germination potential of the coated seeds was lower than germination of non-coated seeds during the first two months of storage, but it was significantly higher for coated compared to non-coated seeds after five months ($p \geq 0.05$). No differences between coated and non-coated seeds were observed at three and four months of storage (Fig. 17a). Seed vigor (Fig. 17b) followed a similar pattern. Coated seeds had lower vigor than non-coated ones ($p \geq 0.05$) only in the first month of storage. From two to four months, there was no difference between coated and non-coated seeds. However, after the fifth month, coated seeds had significantly higher vigor ($p \geq 0.05$) than the non-coated controls.

As vigor and viability decreased, a significant increase in the percentage of deteriorated seeds occurred (Fig. 17c). After six months, both seed viability and vigor were 0% in non-coated seeds compared to 47 and 37% for coated seeds, respectively. The apparent discrepancy between the results of the tetrazolium and the standard germination tests is in part explained by the differences in the percentage of hard (impermeable) seeds, which was higher in the tetrazolium test.

Emergence in sand for coated was lower than for the non-coated seeds ($p \geq 0.05$) when measured before and at one month of storage (Table 21). There was no difference between coated and non-coated seeds at two and three months. However, after four months coated seeds had significantly higher percentage of emergence than the non-coated seeds that showed a 0% emergence after six months of storage at 85% RH and 25°C (Fig. 18).

A




B

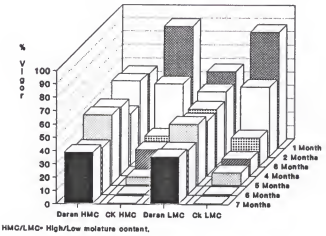
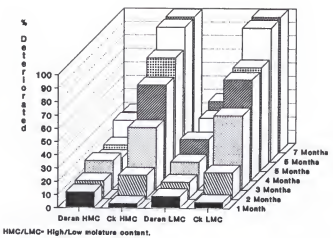



Fig. 17. Effects of seed coating with Daran® 8600 and the initial moisture level of the seeds on several seed quality parameters, as determined by the tetrazolium (TZ) test, during seven months of storage at 85% RH and 25°C. a) germination; b) vigor; c) Deteriorated (non-viable); d) Hard (impermeable) seeds.

C




HMC/LMC= High/Low moisture content.

D

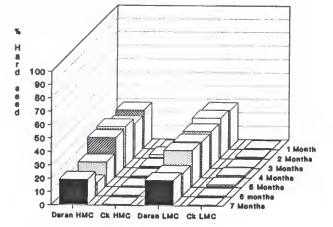



Fig. 17--continued.

Table 21. Effect of polymeric coatings and storage time on the emergence in sand of 'Tracy-M' soybean seeds stored for seven months at 85% RH at 25°C.

| Coating | Months of Storage | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Daran® 8600 | 8.5 | 80.8 | 78.2 | 75.3 | 72.0 | 74.0 | 60.3 | 60.8 |
| Non-coated | 97.8 | 98.0 | 85.2 | 49.0 | 25.3 | 11.8 | 0.0 | 0.0 |
| $LSD_{(0.05)}$ | 2.8 | 3.4 | 14.2 | 31.7 | 34.0 | 12.9 | 4.7 | 5.5 |

In the combined analysis of variance (Table 22), the effects of the coating treatments, time of storage and their interactions had the largest mean square values. However, it should be emphasized that before storage, the coating had detrimental effect on germination because of lower imbibition. Benefits of the coating were showed after three months of storage, when non-coated seeds lost their viability rapidly, reaching 0% in six months (Table 21). The lowest mean square values were those for the initial moisture content of the seeds, and its interaction with the other factors.

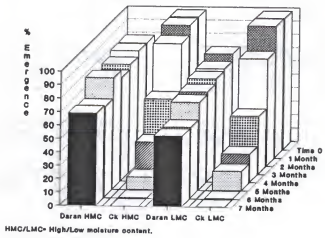



Fig. 18. Emergence in sand of 'Tracy-M' soybean seeds coated with polymer and stored at 85% RH and 25°C, for seven months.

Table 22. Analysis of variance for emergence in sand of 'Tracy-M' soybean seeds coated with polymers and stored at 85% RH and 25°C, for seven months.

| Source of Variation | df | Mean Squares |
|---|---|---|
| Model | 33 | 3462 *** |
| Blocks | (2) | 2186 *** |
| Coating | (1) | 7651 *** |
| Moisture | (1) | 1155 * |
| Coat*Moist | (1) | 319 ns |
| Time | (7) | 5755 *** |
| Coat*Time | (7) | 8507 *** |
| Moist*Time | (7) | 59 ns |
| Coat*Moist*Time | (7) | 69 ns |
| Error | 62 | 213 |
| C.V. (%) | | 26 |

*,*** Significant at the 0.05 and 0.001 probability levels, respectively.

## SUMMARY AND CONCLUSIONS

Seed quality of soybeans deteriorates during the many different phases of production and storage following physiological maturity. These phases include field storage, harvesting and conditioning, storage, transport, handling, and finally, the planting operation. A successful seed-production program is not complete until the seeds are actually planted in the field and produce agronomically acceptable stands. Soybean seeds are, in nature, short-lived and their storability is influenced by the degree to which the seeds have deteriorated prior to storage. However, in the humid tropics, even high seed quality at the time of harvest may not confer an adequate storage life for soybean. Soybean seeds in open storage, will rapidly absorb moisture from the environment and deteriorate. The deterioration processes are enhanced by high temperatures and humidities and the development of storage molds.

In some regions of the world, where conditioned storage, with controlled temperature and relative humidity, are not economically feasible or sometimes not available, seed coating with polymers would be a practical solution. Unfortunately, most of the research published on seed coating with polymers or other hydrophobic materials, have not shown sufficient advantages for long-term storage.

In this study, different coating materials and methods of application were tested for periods up to ten months of storage. Only two polymer formulations showed potential as moisture barriers during storage at high relative humidity. These polymers, Daran® 220 and Daran® 8600, were then further evaluated by different methods of application (manual or using a Vector Freund Hi-Coater®).

In the first two experiments, the polymers were applied at rates of 50 g $kg^{-1}$ seed and seeds of 'Century-84' when coated, had moisture contents $\geq$ 100 g $kg^{-1}$ fw. All polymeric coatings reduced the rates of moisture exchange of the seeds with the environment, except Daran® 8600, when talcum powder was not added in the treatments. This polymer caused excessive seed agglomeration and the coat was damaged when the seeds broke apart, as illustrated in Figure 2. Those seeds with damaged synthetic coats, exchanged moisture with the environment at rates similar to the non-coated ones and deteriorated faster than the other coated seeds. Daran® 220 either alone or in combination with the fungicide TBZ, slowed the rates of moisture exchange with the environment; however, the polymeric coating apparently was too hard and caused excessive abnormality in the seedlings.

Seeds coated with Daran® 8600 with the addition of talcum powder showed some advantage over the other coating treatments. However, germination and vigor levels were too low to be accepted agronomically. The cause(s) of the loss of viability in coated seeds remained unresolved. It is possible that the initial moisture content of the seeds, when they were coated, was too high ($\geq$ 100 g $kg^{-1}$ fw). This

perhaps, violated one of the basic principles of seed science and technology "for sealed storage, soybean seed moisture content should be below 90 g $kg^{-1}$ fw" (Delouche et al., 1973; Delouch, 1975; Copeland and McDonald, 1985; and, Bewly and Black, 1985). Also, there is a possibility that the amount of polymer used on 'Century-84' seeds (50 g $kg^{-1}$ seed) was too high.

For this reason, new experiments were designed at the University of Florida. In the second experiment, those seeds coated in Cedar Rapids and used in the first experiment at Iowa State University were re-evaluated. Basically, the same results were obtained. Seeds coated with Daran® 8600 plus talcum powder showed lower rates of moisture uptake than seeds coated with Daran® 8600 alone, either applied manually (UF technique), or with the Vector Freund Hi-Coater® at the Vector Laboratories, in Cedar Rapids, Iowa. Seed quality during storage followed the same trends observed previously.

The third experiment with 'Tracy-M' seeds was an attempt to resolve the problems with the coating treatments, by manipulating the seed moisture content, at the time of coating, and the amount of polymer applied.

Fortunately, the results here obtained with 'Tracy-M' seeds, were completely different from those obtained with seeds of 'Century-84' in experiments I (ISU) and II (UF). Daran® 8600 applied at rate of 30 g $kg^{-1}$ seed in the Vector Freund Hi-Coater® with addition of talcum powder, resulted in lower germination before storage. However, after two months no difference between coated and non-coated seeds was observed, until the fourth month. After that, coated seeds independent

of their initial moisture level, maintained their viability whereas non-coated seeds were non-viable after six months. Although there was no statistical difference between the two initial moisture levels, seeds with the higher moisture contents at the time of coating (84 g $kg^{-1}$ fw) performed better than those with lower initial moisture contents (58 g $kg^{-1}$ fw).

In conclusion, under the conditions, cultivars and year of the present study, the efficacy of polymers as moisture barriers to maintain seed viability during storage was demonstrated. Daran® 8600 at a rate of 30 g $kg^{-1}$ seed when applied with the Vector Freund Hi-Coater® equipment, significantly reduced the rate of moisture uptake from the environment and maintained seed quality. To assure the integrity of the coating, talcum powder must be added during the coating process. The addition of talcum was found to prevent the agglomeration of the seeds that damages the coating when the seeds break apart. The initial moisture content of the seeds is critical and should be kept between 58 and 84 g $kg^{-1}$ fw, preferably in the upper limits.

## APPENDIX

Table A. Germination of 'Corsoy-79' soybean seeds stored for 26 weeks in two different environments, after coating[a] with several materials and polymers.

| Coating Treatment | Months of Storage / Environment | | | |
|---|---|---|---|---|
| | 3 Months | | 6 Months | |
| | 50% RH | 90% RH | 50% RH | 90% RH |
| | ----------% | | | |
| Eudragit® | 96 | 98 | 95 | 0 |
| Daran® 220 | 97 | 98 | 96 | 0 |
| Antifoam B® | 97 | 98 | 95 | 0 |
| Antifoam B® (50%) | 98 | 96 | 96 | 0 |
| Antifoam A® | 96 | 96 | 96 | 0 |
| Antifoam A® (50%) | 96 | 98 | 94 | 0 |
| Slipicone® | 95 | 97 | 96 | 0 |
| Ze® | 97 | 96 | 96 | 0 |
| Silicone Oil | 98 | 97 | 95 | 0 |
| Non-coated (Control) | 96 | 99 | 97 | 0 |

[a] Materials were applied with a Gustafson Batch Laboratory Treater. Seeds were held in a rotating drum and the chemicals were applied with a spray gun.

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BIOGRAPHICAL SKETCH

Ademir Assis Henning was born on March 14, 1950, in Rio Negro, State of Paraná, Brazil. He completed his high school at the Colégio Estadual Pres. "Caetano Munhoz da Rocha" in Rio Negro, State of Paraná, in December 1968. In 1973, he received his Bachelor of Science degree in agronomy from the "Federal University of Paraná" in Curitiba, state of Paraná. From March 1974 to August 1975, he worked for the Ministry of Agriculture/AGIPLAN (National Seed Program). From August 1975 to August 1977 he worked at Mississippi State University towards a Master of Science degree in plant pathology, with a minor in weed science.

He returned to Brazil in August 1977 and joined the Brazilian Corporation for Agricultural Research (EMBRAPA) beginning his research work at the Experiment Station in Campos, state of Rio de Janeiro. In July 1978 he joined the "Foundation Seed Production Service of EMBRAPA" in Brasilia - DF. working with basic seed production. In July 1979 he was in charge of the seed pathology laboratory of the National Center for Soybean Research EMBRAPA/CNPS, in Londrina, State of Paraná. From July 1979 to February 1982 he conducted research on seed pathology of soybean and sunflower. From March to December, 1982 he studied seed pathology at the Danish Institute of Seed Pathology in Copenhagen, Denmark. He went back to Brazil and continued his research in the seed pathology until January, 1986.

In January 1986, he was granted a scholarship from EMBRAPA to pursue a Ph.D. program at Iowa State University starting research on seed encapsulation with polymers. In August 1988, he transferred to the University of Florida to continue his research and get his Ph.D. in agronomy. He is currently a Ph.D. candidate, and upon completion of his graduate work, will return to the National Soybean Center in Londrina, where he will continue to conduct research on soybean seed pathology and physiology.

In the Spring of 1990 he received the Fred G. Hull Agronomy Research and Achievement Award from the Institute of Food and Agricultural Sciences and the Department of Agronomy, University of Florida. This prize was awarded in recognition of his outstanding research and his leadership and services in the field of agronomy.

He is a member of the American Society of Agronomy, Brazilian Association of Seed Technologists, and Brazilian Society of Phytopathology. In 1987 he became a member of the Gamma Sigma Delta, Honor Society of Agriculture, in Iowa.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

S.H. West

Dr. S.H. West, Chairman
Professor of Agronomy

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